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COMMENTS ON BRIEF REPORT BY T.E. GRAEDEL AND L.J. LANZEROTTI 'INTERPLANETARY-PARTICLE ASSOCIATIONS WITH TYPE III SOLAR BURSTS'*

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Graedel and Lanzerotti (1971) (herein referred to as G & L) claim that during the period from May 28 to November 30, 1967 the type III radio burst-interplanetary particle association "...do not support the common belief that interplanetary-particle observations confirm the association of electrons with type III radio bursts." They use three sets of particle data -- ~0.6 and ~1.2 MeV proton data, >300 keV electron data and >40 keV electron data -- in conjunction with decametric wavelength type III bursts reported in Solar-Geophysical Data (U.S. Dept. of Commerce, 1968) and the IAU Quarterly Bulletin on Solar Activity (1968) and satellite radio observations from OGO-5. The basis for their claim is that both the proton data and the >40 keV electron data can be associated with type III bursts, and therefore "The belief that interplanetary electron observations firmly support the electron and type III burst associations ...must be regarded as unproven."

I believe that their conclusion is unfounded for the following reasons:

1. Two (low energy protons and >300 keV electrons) of the three sets of particle data are inappropriate for correlation to type III bursts.
2. Their analysis and interpretation of the correlations are incorrect. The 65% correlation obtained between proton events and type III bursts is what would be expected from random choice of particle onset times under their correlation criteria. The >40 keV electron correlation to type III bursts of 55% is (a) incorrect and should be 58% ± 12%, and (b) is above the correlation of ~42% for randomly chosen onset times. Also the authors used

only part of the published >40 keV electron data; using a full sample and their criteria one would obtain 63% ± 9%.

3. G & L question the validity of the flare associations made for energetic particle events because of the large variation in transit times for the particles from the sun to the earth. I believe that the association of flares to >40 keV electron events are valid and that the variation (1.5 to 80 minutes) is explained by the criteria governing the choice of onset times and by the inherent inaccuracies of listed flare times.

I shall discuss each of these three points in turn.

Inappropriateness of the 0.6 and 1.2 MeV proton and >300 keV electron data

The observations of type III radio bursts from both terrestrial stations and spacecraft clearly indicate that the type III burst exciter speed stays essentially constant from close to the sun to 1 A.U. I quote from the abstract of Fainberg and Stone (1970), who examined 2500 type III burst drift rates by a method independent of a model for electron density along the path traveled by the exciter. "Based on this dependence, a least squares analysis of 2500 drift rates between frequencies in the 2.8 to 0.7 MHz range yields an average exciter speed of 0.38c for the height range from approximately 11 to 30 $R_\odot$. In conjunction with the available determinations of exciter speeds of 0.33c close to the sun, i.e. less than 3 $R_\odot$, and with in situ measurements of 40 keV solar electrons by space probes, the present results suggest that the exciters are electron packets which propagate with

little deceleration over distances of at least 1 AU." Hartz (1969) in a previous paper on hectometer wavelength observations also finds that "The average source drift velocities are found to be about 0.35c, in substantial agreement with results obtained at metric and decametric wavelengths."

Fainberg and Stone (1970) find a spread in frequency-drift rates which can be interpreted as a velocity spread of 0.2 to 0.6c for the exciter. However they believe that the spread is due to streamer density inhomogeneities. Although their analysis is carried out for a type III storm they indicate that preliminary analysis shows that such exciter velocities are also typical of isolated type III bursts.

In view of this evidence for velocities of $\sim$0.37c out to 30 $R_\odot$ (0.14 A.U.) it is clear that the >300 keV electrons ($v \sim 0.77c$) are inappropriate for this analysis.

The 0.6 and 1.2 MeV proton data are also completely irrelevant to the discussion since $v \sim 0.04c$. Presumably the proton data are applicable if, as G & L suggest, the exciter suffers substantial deceleration between the sun and 1 A.U. In fact Kaplan and Tsytovich (1968); Friedman and Hamberger (1969) and Smith (1970a, b) have suggested proton beams for just the reason that there is theoretical evidence indicating that protons will <u>not</u> lost much energy in their generation of plasma waves. Thus any proton observations should be directed at $\sim$50 MeV protons (Smith 1970a). It should also be mentioned here that since the observations are of the first arriving protons after the event at the sun little adiabatic deceleration will be suffered by the protons in their propagation out through the interplanetary medium.

Thus the only relevant data examined here is the >40 keV electron data.

Analysis and interpretation of the particle-type III correlation

G & L obtained a 65% correlation of 0.6 and 1.2 MeV protons with type III bursts using the criteria that the burst occurs 4 ± 1 hour or 5-8 hours before the onset of the event. They obtained a 55% correlation for >40 keV electron events under the criteria that the type III burst occurs with $\frac{1}{2}$ or 1 hour before the electron onset. In order to interpret their results one must ask that percent correlation would be obtained under these criteria for randomly chosen particle event onset times. To obtain this number I have taken the days when events occur and calculated what percent of the total observational time would be covered under the various criteria. Here I have used the IAU Quarterly Bulletin of Solar Activity (1968) listing of decametric bursts. Under the proton criteria, 4 ± 1 hour or 5-8 hours — equivalently 3-8 hours before the proton onset — a 62% correlation would be obtained for randomly chosen onset times compared with 65% obtained by G & L for the observed proton event onsets.

For the electron criteria, 0-1 hour before the electron onset, I obtain 42% for randomly chosen onset times compared to 55% obtained by G & L for actual electron event onsets. In addition, G & L used data from the Weissenau Observatory, which was the only one covering the ~0700-1200 period, to obtain negative correlations in several of the events. The negative correlation for those events is due to the fact that Weissenau does not report decametric bursts

since it only observes in the frequency range 46-540 mHz. Weissenau does report metric wavelength type III bursts for those events. Secondly G & L claim that the period 28 July-4 August 1967 should be treated separately because of the large probability of associating any interplanetary particles with a type III burst. The calculated probability for randomly chosen onset times is 65% for those days. The fact that all 14 electron events during 28 July-4 August are correlated to type III bursts is either a remarkable coincidence or highly significant.

If we throw out those events covered by Weissenau then we obtain 58% ± 12% correlation compared with 42% expected from randomly chosen onset times. This comparison indicates that the correlation is barely significant. However, G & L only used a part of the total published electron event listings (Lin and Anderson, 1970; Lin, 1970). Using all the events observed in 1964-1967, under their criteria I obtain, for 76 events with type III decametric coverage, 48 events with decametric type III bursts occurring within 1 hour before electron onset, 5 with metric type III, 8 with type III slightly longer than 1 hour after (up to 80 minutes) and 15 with none. Thus at least 48/76 = 63% ± 9% of all electron events are associated with type III decametric bursts. This is a very substantial correlation since perhaps on the order of 5-10 events would be expected to originate from flares well beyond the west limb where the accompanying type III radiation would be invisible.

Flare associations

In regard to flare associations for solar particle events, particularly >40 keV electron events, I would like to point out that:

1. It is quite clear that energetic particle events, both proton and electron, which can be identified from their time profile and velocity dispersion to be new impulsive injections of particles from the sun, are indeed produced by solar flares (with the possible exception of very small events).

2. G & L mention the complications in identifying the associated flare which arise from uncertainties in modes of particle propagation and diffusion in the interplanetary medium. These complications are <u>not</u> removed by correlation directly to type III bursts. This fact is implicitly recognized by the authors in their second proton association criteria.

3. Flare associations for >40 keV electron events have <u>not</u> been biased by the size of the flare; in fact Lin (1970) finds that one of the characteristics of electron flares is that they are predominantly importance 1 flares or subflares.

4. The time period between the flare and the >40 keV electron observed at 1 A.U. varies predominantly because the onset of the event is mechanically chosen as the time when the flux has risen above and stays above 1σ above background. If the background is high due to preceding events or if the rise of the event is slow, or if the event is weak the onset time will be chosen somewhat later. No extrapolation to zero flux has been used. In addition the onset time depends on the energy of the electrons. Furthermore

the timing accuracy of optical flare listings is on the order of ± 5 minutes — stations rarely agree among themselves to better than that. It is therefore quite reasonable to expect variations of 1.5 to 83 minutes (corresponding to 10 to 91 minutes travel time from the sun to the earth) between flare and electron onset at 1 A.U. The events which exhibit a rapid rise and for which accurate x-ray data exist always appear to have their onset within 40 minutes of the x-ray burst maximum.

5. Previous efforts to examine the question of type III burst correlation to >40 keV solar electron events have been based on the following criterion: "A radio or x-ray event was considered to be associated with the electron event if it occurred within ± 2 minutes of the period between the start and maximum of the electron flare event. The flare end time was not used because of its variability from one observatory to another and because, in many cases, the electron onset at 1 A.U. occurred before the end of the flare." (Lin, 1970) Using this same criteria and examining all flares from the Solar-Geophysical Data (U.S. Dept. of Commerce, 1968) and all type III bursts listed in the IAU Quarterly Bulletin on Solar Activity (1968), I find:

	Quiet Period April 1-20, 1967	Disturbed Period July 22-31, 1967
Total number of flares	394	555
Number of flares for which radio data is not available	124	92
Number of flares with type III burst	$\frac{51}{270} = 19\%$	$\frac{193}{463} = 40\%$

Number of electron event flares with type III burst (from Lin, 1970) $\frac{46}{56} = 82\%$

It is clear that the results are highly significant. Two points should be noted here: (a) contrary to G & L's claim, the association of particle events with flares does not automatically produce an association with type III bursts, even in highly disturbed times; and (b) the association of type III bursts with electron event flares is even higher than when the type III bursts were directly compared to electron events. This is partly because events which are not identified with a visible flare may be from flares over the limb whose type III emission is not observed.

In summary, I believe that G & L's conclusion is incorrect and that if the analysis is carried out correctly then the results actually support the association of type III bursts and >40 keV electron events.

One question which remains is that the number of type III radio bursts far exceeds the number of >40 keV electron events observed at 1 A.U. However, any correlations of the two phenomena must take into account:

1. the location of the type III burst at the sun,
2. the relative sensitivity for detection of type III bursts and electrons,
3. the possibility that type III burst particles are stopped high in the corona and do not escape.

Recently, Alvarez et al. (1972) have compared intense type III bursts observed by OGO-5 at 350 kHz (corresponding to a distance of ~50 $R_\odot$ away from the sun) to electron events observed at 1 A.U. They find

that essentially a one-to-one correlation (26/28) exists between these distant type III bursts and >40 keV electron events above detector threshold, for bursts from flares west of W10° solar longitude.

I would also like to correct one particular misquotation by G & L in their article: Lin (1970) did not suggest "...the possibility of similar behavior for >40 and >300 keV electrons." Quite the contrary the article clearly points out the difference between the relativistic electron component (which only accompany proton events) and the >40 keV electron component and notes (with reference to electrons) "...with the exception of a very few events not observed at 3-10 MeV energy all these 0.3-0.9 MeV events are observed only during proton events." (Lin, 1970)

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